COMPARISON OF BASIC MAINTENANCE CONCEPTS USING WITNESS

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Maintenance is a complex, extensive and important issue in terms of its impact on the quality of manufactured products or services provided in all areas of industry. The importance of predictive maintenance for the industry in the 21st century is crucial. However, the right approach to maintenance management is often underestimated in many companies today, although it can have a very positive effect on the company's efficiency. Using the example of a practical application, the paper includes a comparison of three main maintenance concepts – classical (reactive), planned, predictive through the simulation software Witness. Maintenance concepts are compared in terms of their ability to solve and eliminate failures that occur in production facilities during operation.

KEYWORDS

Maintenance, Predictive Maintenance, Maintenance concepts, Dynamic Simulation, Witness, Production

1 INTRODUCTION

Nowadays, there is a dynamic development, the emergence of new advanced technologies that increase the efficiency of everyday life. It is also reflected in industrial production. The goal of every industrial enterprise is to increase the efficiency of production processes and thus the possibility to succeed in a competitive environment. One of the areas that can significantly increase a company's production efficiency is setting up the right maintenance management approach. This issue is a complex, large and important area that directly impacts the quality of products produced and service delivery in all areas of industry. [Cada 2003] Maintenance management should be systematic. Its implementation into corporate management objectives is necessary. A number of maintenance philosophies (TPM, RCM, RBI) are used to improve maintenance, but they are often implementation-based only, without full integration into existing maintenance management systems. [Sajdlerova 2020]

This paper focuses on a comparison of known maintenance approaches. In particular, the focus will be on predictive maintenance and its relevance to the 21st-century industry. Simulation software was used to compare the different maintenance concepts.

2 MAINTENANCE CONCEPTS AND APPROACHES

Maintenance can be defined as a set of technical, managerial and administrative measures applied to a given piece of equipment throughout its life cycle to maintain the equipment in a state where it is capable of performing the required activity at a given quality. [EN 13306, 2018] The main purpose of maintenance is to increase the operability and reliability of machinery and increase the interval between maintenance interventions.

There are different methods and strategies to approach maintenance. They differ not only in the approach but, above all, in their resulting efficiency and cost-effectiveness. In general, with regard to the occurrence of the actual trigger event - machine failure - we can approach maintenance in two basic ways:

- reactive - repair is only addressed when a failure occurs;
- proactive - a proactive approach at the stage before a failure or problem occurs.

A **reactive approach to maintenance** involves a method of dealing with a fault after the problem has already occurred. It leads to frequent breakdowns, long downtimes. It also leads to reduced production targets and significant safety risks. In the short term, this approach to maintenance may be seen by some as less costly compared to a proactive approach. However, in the longer term, because the root causes of failures are not sought, they tend to occur more frequently, so this approach may be ineffective and unreliable. [Legat 2013]

Proactive maintenance is a comprehensive approach that requires all stakeholders to work together to ensure the highest possible level of management and coordination of maintenance systems.

It includes the following strategies and methodologies for the concept of maintenance:

- Time-Based Maintenance,
    - preventive and planned maintenance,
    - predictive maintenance,
- maintenance focused on the company as a whole (Total Productive Maintenance)
- Reliability Centred Maintenance,
- Risk Centred Maintenance. [Deighton 2016]

Risk Centred Maintenance. [Deighton 2016] **Preventive and planned maintenance** is one of the first approaches in the proactive maintenance principles and one of the most effective and utilized. It is time-oriented, and the key factors are prevention and regularity. This method of maintenance includes two active components of activities without direct intervention - equipment monitoring and inspection and activities with direct intervention - preventive repairs [Deighton 2016]. The success rate of a properly set up preventive maintenance system is measurable by increasing equipment availability, increasing the company productivity and reducing the time taken to fix faults. [Dougherty 2020] Preventive maintenance can also have its negatives if it is performed too early or too late. Thus, resources are not used efficiently. This occurs when replacement and repair are carried out at regular intervals but without regard to the actual current condition. [Capehart 2015]

Predictive maintenance is an important method of maintenance. It makes it possible to predict problems that may occur in the production process well in advance. It is based on monitoring the actual condition of the equipment during operation and using statistical algorithms to predict when maintenance needs to be carried out to minimise disruption to the production process. The benefits are then savings in service costs, time savings in repairs, increased availability of production equipment and minimization of unexpected equipment failure. [Deighton 2016] Predictive maintenance is becoming one of the important components of the 21st-century industry. The potential usage is directly proportional to the level of digitization of a given company. This is where full automation, the interconnection of electrical equipment recording real-time process status information, and the ability to communicate with each other via the Internet of Things (IoT) technology in real-time all play a role. [Tureckova 2020]

Total Productive Maintenance (TPM) is an approach to maintenance that requires the maximum active involvement of all employees, from operators to management. [Necas 2020] The main objective is to achieve the highest possible efficiency in the use of machinery and equipment. It is a methodology for improving the maintenance system, a philosophy that must be adopted, understood and adhered to by all members of a given company.

Reliability Centred Maintenance (RCM) is a modern method of reliability-focused maintenance. The aim is to identify the causes of equipment failures and then seek to eliminate them. It is a proactive method, increasing machine reliability at the lowest possible cost.

3 DYNAMIC SIMULATION

Simulation methods together with predictive technologies represent significant sources of savings for many companies. Strengthening competitiveness and maintaining high levels of supplier service and cost reduction are important factors to which companies must respond. Dynamic simulation thus provides the opportunity to find new and innovative solutions and verify real requirements using Witness simulation. The principle of simulation is simple. The aim is to mimic the real environment and to make different experimental changes and evaluate variations in system behaviour. The advantage is that it is very easy to verify the input hypotheses that have been obtained from theoretical knowledge [Schindlerova 2020].

4 CASE STUDY - COMPARING MAINTENANCE CONCEPTS

The case study focuses on the comparison of predictive, planned and conventional maintenance concepts based on industrial engineering methods using dynamic simulation in Witness software. In the course of the experiment, the different methodologies were compared based on the quantity produced, the organization and readiness of the maintenance team in eliminating faults, as well as the verification and determination of the optimal number of maintenance operators. Time was an important parameter in the verification through simulation. The aim was to validate the theoretical knowledge in the field of maintenance within the expected assumptions of better organization and increased performance of production lines using predictive maintenance with respect to planned and conventional maintenance. [Carbol 2021]

The case study was prepared on the basis of data on the failure rate of the production line for the production and packaging of ground coffee provided by the given company.

The course and the individual phases of the experiment were guided by the methodological procedure that was set up at the beginning. A diagram of the methodology for comparing the above maintenance concepts is shown in Fig. 1 [Carbol 2021].

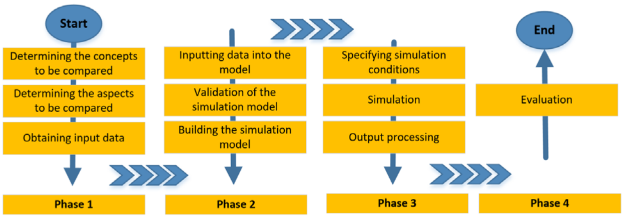


Figure 1. Schematic of the methodological workflow for comparing maintenance concepts [Carbol 2021]

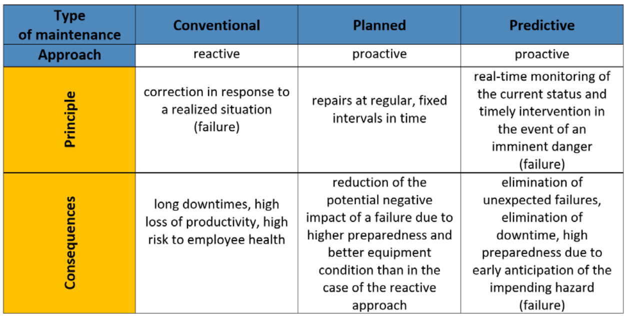
The experiment compared the three aforementioned concepts of predictive, planned and conventional maintenance. A brief overview of the different maintenance methods and their characteristics is given in Fig. 2.

It is evident that the most appropriate approach to maintenance in terms of the highest productivity and highest work safety can be expected from predictive maintenance.

While planned maintenance will not eliminate unexpected breakdowns and the resulting loss of productivity, its proactive approach will improve the technical condition of all equipment and make operators better prepared to deal with unexpected breakdowns.

The reactive approach to maintenance can lead to an increased risk of fatal breakdowns and thus have a negative impact on the productivity of the production process and the safety of workers.

The above hypotheses will be verified and evaluated using dynamic simulation.



Type of maintenance	Conventional	Planned	Predictive
Approach	reactive	proactive	proactive
Principle	correction in response to a realized situation (failure)	repairs at regular, fixed intervals in time	real-time monitoring of the current status and timely intervention in the event of an imminent danger (failure)
Consequences	long downtimes, high loss of productivity, high risk to employee health	reduction of the potential negative impact of a failure due to higher preparedness and better equipment condition than in the case of the reactive approach	elimination of unexpected failures, elimination of downtime, high preparedness due to early anticipation of the impending hazard (failure)

Figure 2. A brief overview of the basic characteristics of the compared maintenance concepts [Carbol 2021]

4.1 *Phase 1 - Input analysis*

In the initial phase of the experiment, it was necessary to identify the input Data, analyse the production process and define the relevant monitored parameters. A crucial factor that affects labour productivity is the time when the production equipment is in operation and adds value or when the equipment is out of operation and thus does not add value to the final product. If the company uses production time efficiently, it will achieve high labour productivity and become competitive.

The maintenance concepts were compared in terms of their ability to address and eliminate equipment failures within the production process effectively.

The production and packaging process of ground coffee is shown in Fig. 3. The line contains 7 production devices. [Carbol 2021]

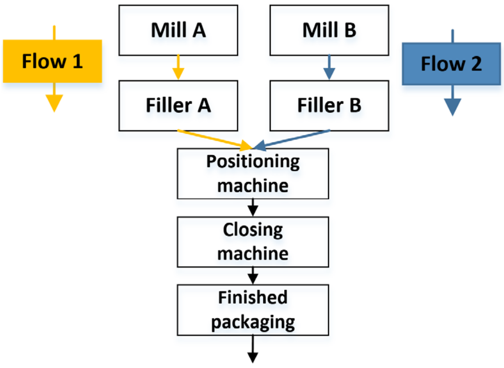
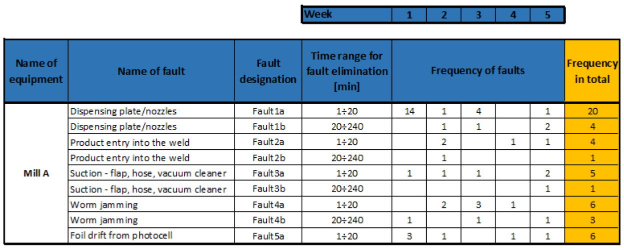


Figure 3. Schematic of the production line [Carbol 2021]

The input data on the production line failure rate contains a set of lists of failures that occurred during the monitored period of 5 weeks, when the line was in operation five days a week, 24 hours a day. The frequency of occurrence during the period and the time taken to rectify the fault is also included. An example of the occurrence of faults for “Mill A” equipment is shown in Fig. 4.



Name of equipment	Name of fault	Fault designation	Time range for fault elimination [min]	Frequency of faults					Frequency in total
			Week	1	2	3	4	5	
Mill A	Dispensing plate/nozzles	Fault1a	1÷20	14	1	4		1	20
	Dispensing plate/nozzles	Fault1b	20÷240		1	1		2	4
	Product entry into the weld	Fault2a	1÷20		2		1	1	4
	Product entry into the weld	Fault2b	20÷240		1				1
	Suction - flap, hose, vacuum cleaner	Fault3a	1÷20	1	1	1		2	5
	Suction - flap, hose, vacuum cleaner	Fault3b	20÷240					1	1
	Worm jamming	Fault4a	1÷20		2	3	1		6
	Worm jamming	Fault4b	20÷240	1		1		1	3
	Foil drift from photocell	Fault5a	1÷20	3	1		1	1	6

Figure 4. Occurrence of faults at the "Mill A" equipment [Carbol 2021]

The different types of failures showed two different time intervals for their removal:

- Minor faults - repairable from 1 to 20 minutes, minor intervention, e.g. configuration, calibration, etc.
- Serious faults - repairable from 20 - 240 minutes, significant intervention, e.g. replacement of a component, etc.

This state of maintenance corresponds to a reactive approach, where there are no defined steps in the maintenance as a whole, there is no system, the equipment is repaired only after a failure.

4.2 *Phase 2 - Preparation of the simulation model*

In the second phase, it was necessary to build a simulation model, verify the accuracy of the model and then input data on the failure rate of the machines, i.e. the frequency of occurrence of failures and the length of the interval for their removal.

The following steps were defined in the development of the simulation model:

- considering how the model should be implemented,
- insertion of the necessary elements (machinery, equipment, labour, etc.),
- defining parameters for individual elements of the simulation model (names and production times),
- defining logic and links between objects within the simulation model,
- verification of the correctness of the simulation model function with mathematical calculation.

Figure 5 shows the simulation model in the Witness environment. Subsequently, data characterizing the failure rate of the production machines, namely the frequency of occurrence of failures and the length of the time interval for their elimination, were inserted into the simulation model. At the end of the second phase, roles were defined for the maintenance team that will be in charge of dealing with faults occurring on the machines of the production lines.

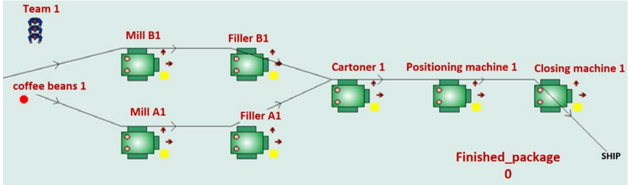


Figure 5. Simulation model of the production line [Carbol 2021]

4.3 *Phase 3 - Simulation flow*

In the next phase, the simulation conditions were determined and refined. The hypotheses of the expected simulation results were established.

The simulation model was created for three production lines, and each represented one maintenance approach as follows:

- Line 1 - Conventional (reactive maintenance),
- Line 2 - planned maintenance,
- Line 3 - predictive maintenance.

Each of the lines includes seven production devices (machines), which have a clearly defined production time and failure rate. The data was obtained by direct observation of the production lines in practice. The failure rate was defined by two parameters:

- frequency of occurrence of disorders,
- the time interval to clear the fault.

Specification of simulation conditions

Based on the research of theoretical knowledge of the studied maintenance approaches, the simulation conditions were specified:

a) Length of the simulated period
  - short-term simulation - 2 months of the production, i.e. 57,600 minutes;
  - long-term simulation - 1 year of production, i.e. 345,600 minutes.

b) Variable number of maintenance team members - simulation scenarios for predictive maintenance
  - maintenance team consisting of 1 member,
  - maintenance team consisting of 2 members,
  - maintenance team consisting of 3 members,
  - maintenance team consisting of 4 members,
  - maintenance team consisting of 5 members.

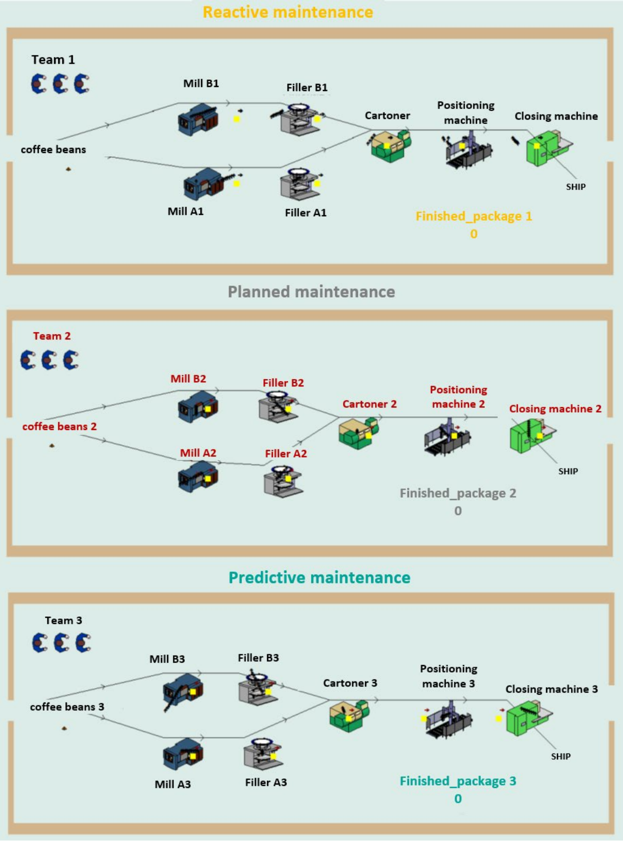


Figure 6. Individual simulation models of the production line for the compared maintenance concepts [Carbol 2021]

The individual simulation models for the compared maintenance concepts are shown in Fig. 6.

4.4 *Phase 4 - Interpretation of results*

In the final phase of the experiment, the different maintenance concepts were compared based on the simulation conditions set out above.

Length of the simulated period

Based on the simulation, the results of the short-term simulation (2 months) and long-term simulation (1 year) were evaluated. It was found that when comparing the different maintenance concepts, different amounts of coffee could be produced over the observed (simulated) period. The results for the short-term simulation are presented in Table 1.

	Conventional maintenance	Planned maintenance	Predictive Maintenance
Number of packages produced [pcs]	**80 340**	**90 846**	**98 772**
Average production time per pack [min]	**4.63**	**4.22**	**3.95**

Table 1. Overview of coffee packages produced on production lines during two months of production [Carbol 2021]

The table shows that using the predictive maintenance concept, it will be possible to produce 18 432 more packs than with conventional maintenance. From the perspective of the long-term simulation, there were no significant differences between the maintenance concepts in terms of production productivity. The results were comparable to the short-term simulation.

When comparing the observed production line utilization during the simulation period (Fig. 7), it can be seen that the difference between the short-term and long-term simulation is not significant. This result is due to the fact that a long period (2 months) was chosen. The failure data of the production line was collected for a period of 5 weeks, so it could be expected that if the length of the simulation period was set above the five weeks, all defined failures would manifest themselves. It can be seen that the fixed frequency of occurrence of failures contributes significantly to the stability of the results at different lengths of the simulated period.

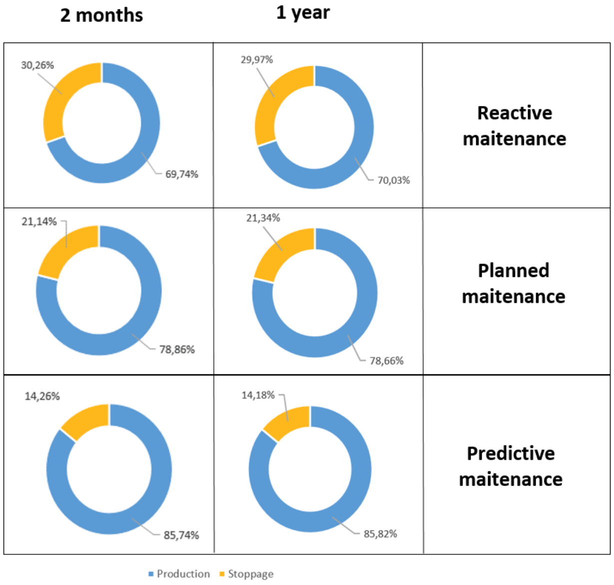


Figure 7: Comparison of observed production line utilization for production, over the simulation period of two months and one year [Carbol 2021]

Variable number of maintenance team members - simulation scenarios for predictive maintenance in short-term simulation

The optimum number of maintenance team members was solved only for predictive maintenance, which was found to be the most appropriate maintenance concept from the above results. The objective was to determine the optimal number of maintenance team members to achieve the best balance between the productivity of the production line and the workload of the individual maintenance operators. The following parameters were set as comparative parameters:

- production line utilization and number of packages produced,
- waiting time for the arrival of the maintenance staff and their workload,
- economic aspect.

Production line utilization and number of packages produced

Production line utilization is a key indicator of equipment performance. It indicates how long the machine was productive and produced the desired product out of the total available time. It can be seen from Fig. 8 that the availability of production equipment increases as the number of maintenance team members increases. The lowest availability was achieved when faults were handled by only one maintenance operator.

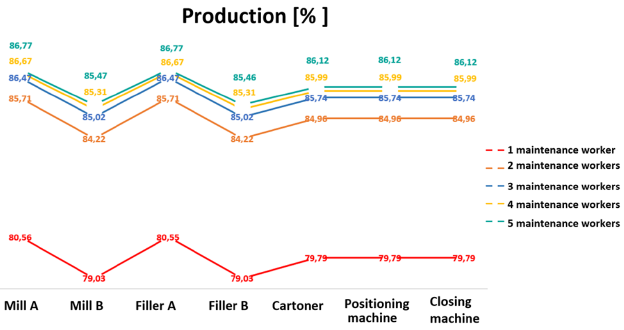


Figure 8. The proportion of utilization of each machine on the production line for predictive maintenance, with different numbers of maintenance team members [Carbol 2021]

As the number of team members grew, the availability of each piece of equipment also increased, resulting in increased productivity. In Fig. 9, the development of the number of coffee packages produced can be observed as a function of the increasing number of maintenance team members. The maximum number of packages of 99 204 for the period under study was produced with the maximum number of maintenance personnel who were responsible for the administration and elimination of faults of the production equipment. When only one maintenance operator was working, production decreased by 7 286 packs of coffee. With the higher number of maintenance operators in the team, although the production volume increased during the period, a significant increase was recorded only in the case of 2 members in the team, by 6.48%. From the number of 3 members in the team, the increase in production volume compared to 2 members was only in the range of 0.92-1.45%.

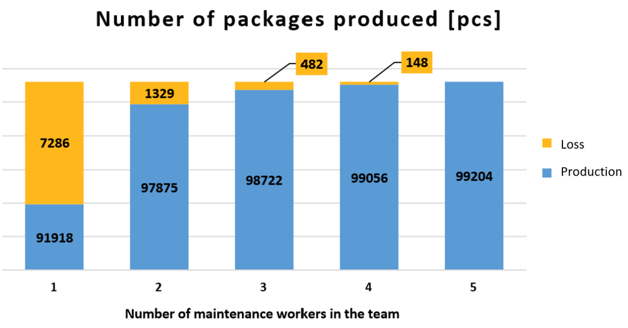


Figure 9. Number of packages produced on the lines, with different numbers of maintenance team members [Carbol 2021]

Waiting time for the arrival of a maintenance worker and their workload

The waiting time for the arrival of a maintenance worker is an important parameter that increases the time to fix the fault. Fig. 10 shows the recalculation of the percentage of the specific time when the production line waits for the arrival of a maintenance worker to a fault. Again, it can be seen that there is a relatively long waiting time for repair when only one operator is working. If two machines are at fault simultaneously, then there is a significant blocking of production.

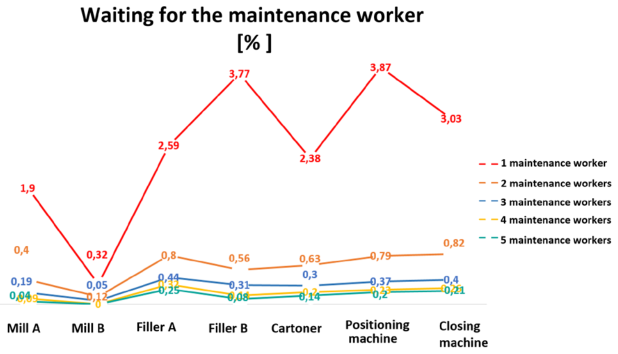


Figure 10: Changes in the proportion of waiting time for maintenance workers on lines under predictive maintenance for different numbers of maintenance team members over the whole period under study [Carbol 2021]

An important indicator for determining the optimal number of maintenance team members is their workload. Table 2 gives an overview of the distribution of the total number of repairs among the individual members of the maintenance teams.

Maintenance workers' workload repairs made					
Order of maintenance workers	**1.**	**2.**	**3.**	**4.**	**5.**
Team 1	1 860	X	X	X	X
Team 2	1 421	439	X	X	X
Team 3	1 354	398	108	X	X
Team 4	1 338	387	88	47	X
Team 5	1 328	367	85	41	39

Table 2. Distribution of repairs performed among individual maintenance workers within the given maintenance teams [Carbol 2021]

The table shows that the workload of the maintenance team members is very uneven. It is due to the fact that in the simulation model, the first team member always has priority in fault handling. So, if a subsequent fault occurs while the previous fault is cleared, the first team member will again be involved in the fault clearance. Should he/she remain busy, the second team member will resolve the fault, etc. It is, therefore, apparent that a two-member team would be the most appropriate.

Economic aspect

The above conclusions were subsequently verified from an economic point of view. A simple calculation was carried out in order to determine the economic share of individual maintenance workers in the company's economy. It was based on data obtained during a short-term simulation (2 months). The price of a packet of coffee (CZK 20) and the gross monthly salary of a maintenance worker (CZK 35,000) were determined for the calculations. If we include the compulsory contributions for the employees, the results would be even more significant. Figure 11 shows that one team member can keep the production equipment running and bring in 1.7 million in two months. Since one maintenance worker is the vital minimum for an organization, this value is considered as a basis for deciding the optimal number of team members. When three team members are used, we are already running into a loss, which increases further as the number of members increases.

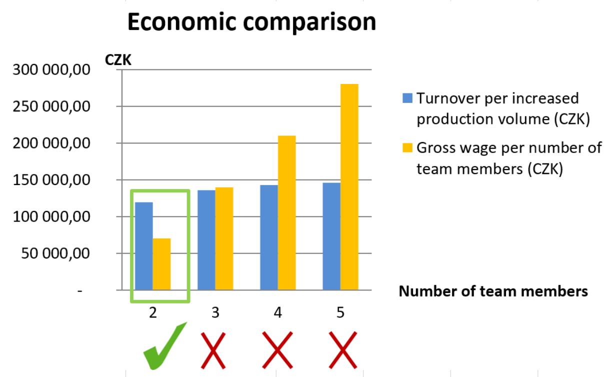


Figure 11. Economic comparison per number of team members [Carbol 2021]

This analysis has clearly confirmed that if the company uses only two members of the maintenance team, the prosperity of the company will be ensured. Such a team, according to the data obtained from the simulation, can maintain the entire production line at a sufficient level of productivity. It will also ensure not only sufficient availability of the maintenance operators, who will have enough time to deal with possible breakdowns but also availability in case of absence of one of the workers, e.g. in case of holidays, etc.

5 CONCLUSIONS

The case study focused on a comparison of maintenance concepts, namely conventional, planned and predictive. The theoretical research provided a summary of the knowledge in the field of maintenance and showed how complex and important its role is within the whole spectrum of industry. Based on the methodology, a step-by-step experiment was conducted with logical continuity. The practical part involved building a model of a coffee packaging production line. Production knowledge was obtained about failures during production, and this was then incorporated into the model design in a simulation environment. The results show that predictive maintenance yields 16% higher availability of production equipment compared to conventional maintenance, which results in the production of more packages of ground coffee. Another interesting finding was the ability to simulate a variable number of maintenance team members. Five simulation scenarios were run, and the assumption that the optimal number of maintenance operators would be between 2 and 5 members was confirmed by dynamic simulation. A team consisting of two operators was the most suitable, which was also confirmed by economic considerations. A higher number of operators would no longer bring the desired increase in productivity to the company.

It is evident that today's competitive environment cannot do without advanced technology, and maintenance also has a significant impact on reducing costs, eliminating waste and maintaining or increasing profits. Thus, the hypotheses and theoretical findings have clearly confirmed the importance of predictive maintenance, which should be used by companies.

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